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VARIATIONS IN BREEDING BALD EAGLE RESPONSES TO JETS, LIGHT PLANES AND HELICOPTERS

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ABSTRACT.—We analyzed 3122 observations of military jets, light planes and helicopters for three levels of response (none, alert, flight) by breeding Bald Eagles (*Haliaeetus leucocephalus*) at 13 occupied nests in Arizona and six in Michigan, 1983–85 and 1989–90, respectively. Helicopters elicited the greatest frequency of response (47%), followed by jets (31%) and light planes (26%). Frequency of response (23–61%) and frequency of flight (2–13%) both increased through the nesting season from February to June. Distance from eagle to aircraft, duration of overflight and number of aircraft and/or passes were the most important characteristics influencing eagle responses to pooled and individual aircraft types. Classification tree (CART) models for individual aircraft types provide dichotomous keys of distance and secondary variables affecting associated response rates, and should facilitate evaluating aircraft-specific impacts. Our analyses indicate a categorical exclusion of aircraft within 600 m of nest sites would limit Bald Eagle response frequency to 19%.

KEY WORDS: *Bald Eagle;* Haliaeetus leucocephalus; *disturbance; aircraft; behavior; Arizona; Michigan; modeling; classification trees.*

Variaciones en crías de águilas en reacción ha aviones militar, aviones ligeros y helicópteros

RESUMEN.—Nosotros analizamos 3122 observaciones de avión militar, avión ligero y helicóptero para tres niveles de reacción (nada, alerta, volar) de águilas (*Haliaeetus leucocephalus*) de cría en 13 nidos ocupados en Arizona y seis en Michigan, 1983–85 y 1989–1990, respectivamente. Helicópteros le sacaron la reacción con mas frecuencia (47%), seguido por avión militar (31%) y avión ligeros (26%). La frecuencia de reacción (23–61%) y frecuencia de volar (2–13%) aumentaron durante la temporada de poner nidos de febrero ha junio. Distancia de águilas al avión, tiempo en viento, y numeros de aviones y/o pases eran los mas importantes característicos influyendo la respuesta de águilas ha grupos o solos tipos de aviones. Modelos (CART) con clasificación tres para aviones solos proporcionan llaves dicotomías de distancia y variables secundarias afectando respuestas asociadas, y debe facilitar la evaluación de impactos specificos de aviones. Nuestra análisis indica una exclusión categórico de aviones dentro de 600M de nidos debe limitar la respuesta de frecuencia ha (19%) en águilas.

[Traducción de Raúl De La Garza, Jr.]

Aircraft come into contact with breeding raptors in essentially two nonexclusive ways: first, as a potentially disturbing form of ambient human activity (Smith et al. 1988) and second, as a research/management tool specifically focused on nest overflights to survey breeding populations and monitor reproductive success (Fuller and Mosher 1987). For effects on breeding Bald Eagles (*Haliaeetus leucocephalus*), aircraft have been addressed either passively as part of broader disturbance studies (e.g., Grubb and King 1991, McGarigal et al. 1991) or actively as part of an evaluation of the aircraft type used in the reported study (e.g., Fraser et al. 1985, Watson 1993). However, comparative response data on the three common types of aircraft affecting breeding Bald Eagles and other raptors (low-level military jet fighters, light planes and helicopters) are scarce (Smith et al. 1988, Watson 1993) and have not been collected within the context of a single study.

Our research specifically focused on variation in breeding Bald Eagle responses to the three common types of aircraft. It represented a collation and extension of previously described Bald Eagle/

human disturbance research in Arizona (Grubb and King 1991) and Michigan (Grubb et al. 1992). Although these studies showed aircraft to elicit the lowest response of the five disturbance groups evaluated (vehicle 52–74%, pedestrian 45–72%, aquatic 46–53%, noise 38–54%, aircraft 29–33%), the authors noted any potentially disturbing activity, in excess or under the right conditions, can alter normal behavior or induce nesting failure. However, activities that may not cause nest failure can still detrimentally impact eagles. Low-level overflights have caused Bald Eagles to attack (Fyfe and Olendorff 1976) or avoid (Fraser et al. 1985) the aircraft, or depart the area entirely (Grubb and King 1991), all of which are energetically costly and behaviorally disruptive. In Arizona, the death of a nestling was attributed to frequent helicopter flights <30 m off a cliff nest; this unusual activity kept the adults away for long periods and significantly reduced prey deliveries (L.A. Forbis pers. comm.).

Thus, our standardized assessment of nonfailure-producing effects of the three common aircraft types on Bald Eagle responses should facilitate evaluation of potential aircraft disturbances and encourage disturbance-specific breeding area management.

STUDY AREA

The central Arizona study area was located in Gila, Maricopa and Yavapai counties, primarily along the Salt and Verde River drainages. The area is characterized by clustered mountain ranges and desert basins, with elevations of 500–1500 m (Chronic 1983). All nest sites were associated with riparian vegetation consisting of cottonwood-willow (*Populus fremontii-Salix goodingii*) and mixed broadleaf (*Platanus wrightii, Fraxinus pennsylvanica, Alnus oblongifolia*) series amid prevailing Sonoran desertscrub-Arizona upland or palo verde-mixed cacti (*Cercidium* spp.-*Opuntia* spp.) series (Brown 1982). Most eagle nests were located on 50–100-m cliffs.

The Michigan study area was located in the northern lower peninsula along the Au Sable River in Alcona, Iosco, Oscoda and Otsego counties, and the Manistee River in Manistee County. Terrain was flat to rolling with occasional hills; elevation range was 200–400 m. Vegetation was predominantly continuous mixed hardwood forest of aspen (*Populus grandidentata* and *P. tremuloides*), oak (*Quercus rubra* and *Q. alba*), maple (*Acer rubrum* and *A. saccharum*) and birch (*Betula papyrifera*), with interspersed conifer stands of white (*Pinus strobus*), red (*P. resinosa*) and jack (*P. banksiana*) pine. All eagle nests were in trees, mostly white pine.

METHODS

Because of federal threatened and endangered species restrictions, we observed Bald Eagle responses to passing aircraft opportunistically, with no manipulative experimentation nor direct control of aircraft. We could not govern the number or distribution of aircraft among nest sites, through the breeding seasons, or across years. Nor could we effectively address apparent variation in responsiveness by nest site because of differing numbers, types and timing of aircraft (Table 1). Therefore, after testing for differences in the Arizona and Michigan data sets, we combined observations to maximize sample size for analysis and modeling of response trends. Arizona data ($N = 2848$) were collected during the 1983–85 breeding seasons in the vicinity of 13 Bald Eagle nest sites. Michigan data ($N = 274$) were collected during the 1989–90 breeding seasons around six nest sites. Data collection techniques were identical in both states. The combined sample of 19 nest sites represented ≥45 free-flying Bald Eagles from two populations over five breeding seasons (Table 1).

For seasonal analyses, Michigan data were standardized to Arizona data on the basis of incubation dates; one month was subtracted from Michigan dates to integrate the later breeding season into the predominant sample. For general application beyond these two populations, February to early-March was considered the incubation period; mid-March to May, the nestling period; and early June, the fledging period.

As an alternative to unattainable cause-and-effect testing, we monitored variations in Bald Eagle response severity (none, alert/agitated, flight) and response frequency (% none/any) as aircraft overflights occurred. Alert behavior included head turns, vocalizations and increased movements on or between perches. Grubb and King (1991) and Grubb et al. (1992) detail data collection procedures and analytical methods.

We classified aircraft into three generic types: low-flying, military jet fighters; civilian, propeller-driven, light planes; and helicopters, civilian or military, mostly single-rotor. For all aircraft events within 2000 m of nest sites and less than approximately 305 m overhead (1000 ft, estimated), we recorded distance-from-affected-eagle-to-aircraft (m), duration-of-overflight (min), number-of-units-per-event (aircraft and/or passes overhead), visibility-of-aircraft-to-affected-eagle (none/any), and position-relative-to-affected-eagle (above/below). Distance-to-aircraft was approximated by plotting flight paths on topographic maps and measuring distances to reference eagles. Visibility was based on eagle and aircraft positions relative to obscuring vegetation and terrain features.

Medians were used in summary statistics to represent central tendencies because of skewness in data caused by a preponderance of nearby, short-duration overflights. Frequencies, descriptive statistics, and nonparametric k-sample median and goodness-of-fit tests using the chi-square statistic were calculated with SPSS/PC+ 4.0 (Norusis 1990). We used notched box and whisker plots (Chambers et al. 1983, STSC 1991) to evaluate the relationship between distance-to-aircraft and response severity.

We developed classification and regression tree (CART) models to assess variations in response frequency associated with pooled aircraft (all three types combined with no type distinction), pooled aircraft including aircraft type as a separate variable and for each aircraft type

Table 1. Sample distribution by nest site, minimum number of Bald Eagles, years of data, aircraft type, nesting season month and associated variability in frequency of Bald Eagle response for 3122 observations of military jet fighters, light planes and helicopters near 19 occupied nest sites in Arizona (nests 1–13) and Michigan (nests 14–19), 1983–85 and 1989–90, respectively.

Nest			% Response Frequency[a] (N for Aircraft Type)				% Response Frequency[a] (N for Month)				
Site	BEs	Yrs	Pooled	Jets	Planes	Helos	Feb	Mar	Apr	May	Jun
1	≥2	3	37 (108)	20 (5)	31 (90)	85 (13)	27 (77)	40 (15)	67 (9)	100 (7)	– (0)
2	≥2	3	34 (79)	33 (3)	27 (55)	52 (21)	39 (36)	33 (27)	27 (15)	0 (1)	– (0)
3	≥2	3	44 (188)	57 (14)	38 (143)	64 (31)	33 (49)	40 (89)	62 (50)	– (0)	– (0)
4	≥2	3	51 (215)	28 (40)	55 (122)	60 (53)	40 (126)	69 (58)	65 (23)	63 (8)	– (0)
5	4	1	90 (39)	– (0)	93 (28)	82 (11)	– (0)	50 (2)	96 (28)	78 (9)	– (0)
6	≥3	3	20 (1286)	20 (215)	11 (631)	34 (440)	11 (493)	12 (396)	31 (194)	41 (116)	61 (87)
7	≥2	3	62 (24)	– (0)	58 (12)	67 (12)	77 (13)	46 (11)	– (0)	– (0)	– (0)
8	≥4	3	62 (21)	– (0)	78 (9)	50 (12)	20 (5)	83 (6)	100 (1)	68 (9)	– (0)
9	≥2	3	24 (345)	28 (168)	10 (150)	74 (27)	42 (48)	46 (74)	8 (185)	36 (36)	50 (2)
10	≥2	3	53 (49)	36 (14)	59 (17)	61 (18)	62 (8)	72 (18)	28 (18)	50 (4)	100 (1)
11	≥4	2	90 (39)	93 (14)	86 (21)	100 (1)	86 (7)	88 (25)	100 (2)	100 (5)	– (0)
12	≥2	2	44 (390)	45 (97)	36 (234)	73 (59)	10 (40)	63 (91)	41 (134)	45 (125)	– (0)
13	≥3	2	40 (65)	17 (18)	40 (30)	65 (17)	39 (49)	64 (11)	– (0)	– (0)	– (0)
14	2	1	53 (17)	64 (11)	0 (3)	67 (3)	50 (2)	50 (2)	70 (10)	0 (3)	– (0)
15	2	1	30 (10)	25 (4)	33 (6)	– (0)	– (0)	50 (4)	25 (4)	0 (2)	– (0)
16	1	1	0 (1)	0 (1)	– (0)	– (0)	– (0)	0 (1)	– (0)	– (0)	– (0)
17	1	1	100 (1)	– (0)	100 (1)	– (0)	– (0)	– (0)	– (0)	100 (1)	– (0)
18	2	1	50 (10)	100 (2)	38 (8)	– (0)	– (0)	43 (7)	67 (3)	– (0)	– (0)
19	≥2	2	29 (235)	32 (173)	9 (34)	36 (28)	– (0)	33 (73)	28 (120)	26 (42)	– (0)
19	≥45	3	32 (3122)	31 (779)	26 (1594)	47 (749)	23 (953)	34 (910)	33 (801)	44 (368)	61 (90)

[a] Response frequency (%) = number of responses divided by number of events times 100%.

(California Statistical Software, Inc. 1985; Grubb and King 1991). Classification analysis provides predictive, discriminant models in the form of nonparametric, dichotomous keys (Brieman et al. 1984; Verbyla 1987). For each level (branch) of the model, CART selects the independent (splitting) variable, and the point within its range, that best separate (classify) remaining data into classes of the dependent variable (response in our case). This process of tree growing continues until all data are classified.

Only the classification tree aspects of CART were used in our analyses. The first split in each tree separated the higher response, left side of the models from the lower response, right side. Each variable used in CART was ranked for its splitting ability by assigning the first (primary) splitting variable a value of 100% and expressing the relative value of secondary variables as a percentage of the primary variable.

Cross-validation provided an estimate of classification accuracy (predictability) for each tree on a scale of 0.00–1.00 (Brieman et al. 1984, Verbyla 1987). For this procedure, CART randomly divides the data into 10 subsets, develops a classification tree with nine subsets, estimates tree accuracy by applying it to the withheld subset, then repeats the process until all 10 subsets have been withheld. Averaging results of the 10 mini-tests yields an overall estimate of classification accuracy for the tree developed from the full data set (Steinberg and Colla 1992).

RESULTS

Frequencies for none, alert and flight responses did not differ between state populations of Bald Eagles (Arizona—68, 28, and 4% and Michigan—69, 26, and 5%, respectively; $\chi^2 = 1.19$, $P = 0.55$). Although median distance-to-aircraft for alert response varied between Arizona and Michigan (350 and 500 m, respectively; $\chi^2 = 10.57$, $P < 0.01$), median distances for no response (750 and 800 m; $\chi^2 = 1.45$, $P = 0.23$) and flight response (both 200 m; $\chi^2 < 0.01$, $P = 0.96$) were similar. When "state" was added as an independent variable to the CART analyses, it was not included in the resulting models; state location had no discriminatory value for partitioning Bald Eagle responses to aircraft.

Our combined sample consisted of 51% light planes, 25% military jets and 24% helicopters (N = 3122, Table 2). Median number-of-aircraft and

Table 2. Comparison of disturbance and response characteristics among three types of aircraft for 3122 occurrences within 2000 m of 13 occupied Bald Eagle nests in Arizona and six in Michigan, 1983–85 and 1989–90, respectively.

	Disturbance				No Response		Any Response	
Type	Frequency (no. of events)	Median No. per Event	Median Distance (m)	Median Duration (min)	Frequency (%)[a]	Median Distance (m)	Frequency (%)[a]	Median Distance (m)
Military jets	779	1	500	1	69	600	31	400
Light planes	1594	1	700	1	74	850	26	400
Helicopters	749	1	420	1	53	700	47	250
Total sample	3122	1	600	1	68	800	32	333

[a] Response frequency (%) = number of responses divided by number of events times 100%.

duration (min) were similar for all aircraft types. Helicopters occurred at the closest median distance and had the highest response rate, followed by jets, then light planes. All three types typically occurred closer than the median no-response distance, yet overall response rate was only 32%. Response frequencies at individual nest sites were highly variable but at the 12 sites where all three aircraft occurred, helicopters consistently elicited the highest response (Table 1).

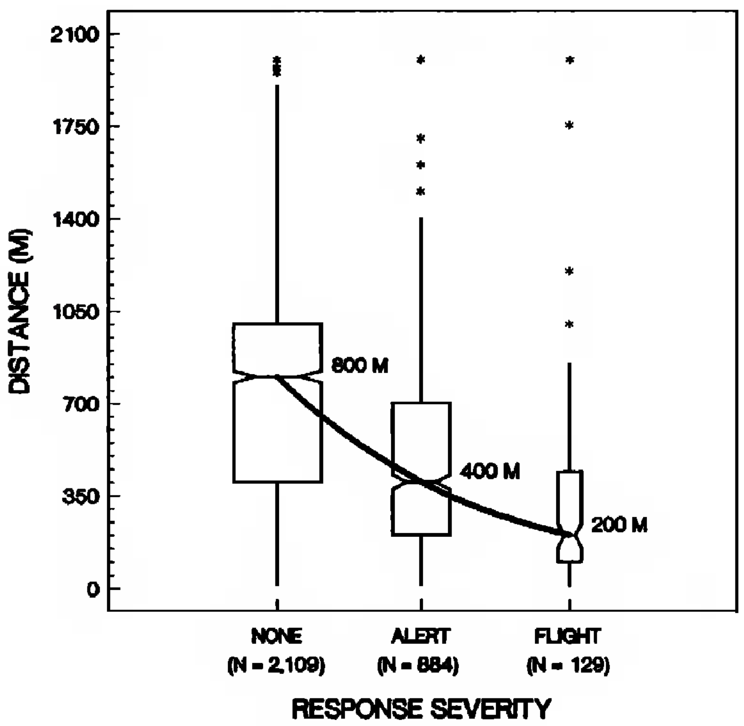

Figure 1. Notched box and whisker plot of median distance to aircraft (military jets, light planes and helicopters) for three levels of response severity for breeding Bald Eagles at 19 occupied nests in Arizona and Michigan, 1983–85 and 1989–90, respectively. Boxes cover middle 50% of data. Tops of boxes indicate the distance within which 75% of recorded responses occurred. Whiskers indicate range but do not exceed 1.5 times box length. Stars represent outlying observations. Box width is proportional to sample size. Center lines are medians, with position indicating skewness. Notches are width of 95% confidence intervals for pairwise comparisons.

Median distance-to-aircraft varied among different levels of response severity, with closer proximity resulting in greater response ($P = 0.05$, Fig. 1). Response frequencies for each type of aircraft also varied at each response level (Fig. 2). Helicopters had the lowest rate of no response ($\chi^2 = 292$, $P < 0.01$) and the highest rates of alert response ($\chi^2 = 124$, $P < 0.01$) and flight response ($\chi^2 = 11.55$, $P < 0.01$). Median distance for flight response was 200 m for all three aircraft types, although frequency of flight from helicopters was more than three times that from jets and planes.

As the nesting season progressed, Bald Eagles responded both more frequently and more severely with more flight. The frequencies of alert and flight responses increased from February to June

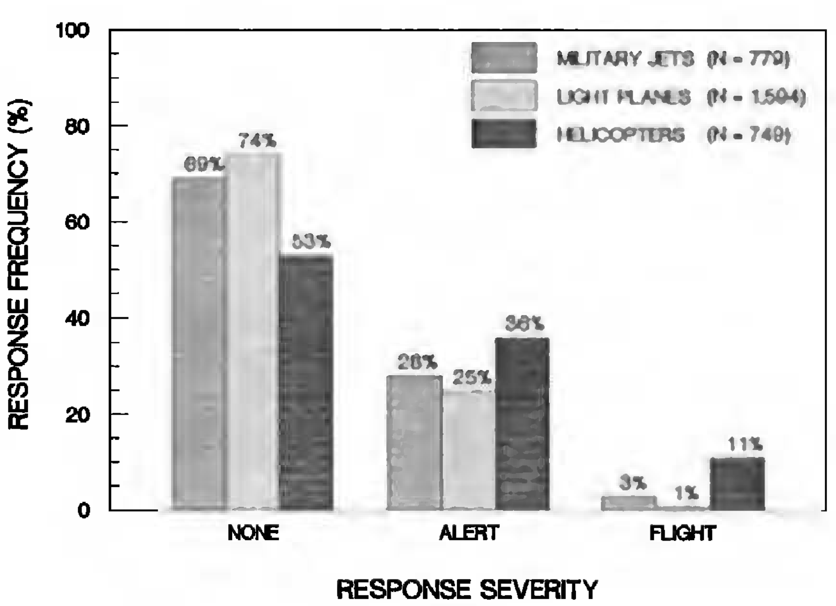

Figure 2. Differing response frequencies among three types of aircraft for three levels of response severity for breeding Bald Eagles at 19 occupied nests in Arizona and Michigan, 1983–85 and 1989–90, respectively.

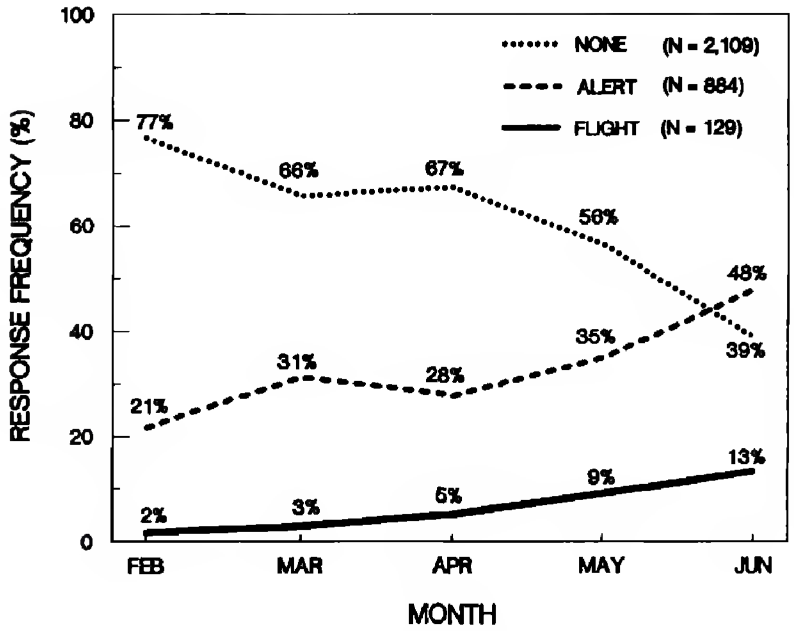

Figure 3. Monthly variations in response frequency for three levels of response severity for breeding Bald Eagles at 19 occupied nests in Arizona and Michigan, 1983–85 and 1989–90, respectively.

(χ^2 = 448 and 1904, respectively; $P < 0.01$), with a compensatory decrease in no-response (χ^2 = 6969, $P < 0.01$; Fig. 3). Seasonal changes in aircraft proximity appeared to have little effect on Bald Eagle responsiveness. Distance-to-pooled-aircraft decreased through the nesting season (χ^2 = 115, $P < 0.01$; Table 3), but median distance-to-aircraft eliciting response did not fluctuate significantly between February and May (median = 350 m; χ^2 = 3.65, P = 0.30).

Although sample sizes became smaller as the nesting season progressed, responsiveness to pooled and individual aircraft types started relatively low during incubation (February), leveled at a higher plateau during the nestling period (March–May) and increased to the highest levels after fledging (June, Table 3). May and June data also indicated that the consistently higher response to helicopters was more a function of aircraft type than distance. In May, when the median distance to both jets and helicopters was 500 m, eagle responses were 37% and 52%, respectively. In June, light planes and helicopters both occurred at 200 m, yet eagle responses were 45% and 84%, respectively.

Frequency of eagle response increased as the frequency of aircraft decreased. Nest site No. 6 had >1200 recorded aircraft overflights, six sites had between 100–400 and 12 sites had <100 (Table 1). Response frequencies for these three groups were 20, 38 and 55%, respectively (χ^2 = 545, $P < 0.01$). Yet, the median distance-to-aircraft-eliciting-response was similar between nest groups: alert response, 300–400 m (χ^2 = 2.25, P = 0.32) and flight response, 150–200 m (χ^2 = 1.82, P = 0.40).

In the CART pooled aircraft model (Fig. 4), dis-

Table 3. Monthly variation[a] in sample sizes, response rates and median distances for 3122 military jet fighters, light planes and helicopters near 19 occupied Bald Eagle nest sites in Arizona and Michigan, 1983–85 and 1989–90, respectively.

	FEB	MAR	APR	MAY	JUN
Military jets					
N	199	209	255	86	30
Median distance (m)	600	500	600	500	300
% Response	23	38	27	37	53
Light planes					
N	515	503	403	144	29
Median distance	850	700	700	600	200
% Response	20	26	28	40	45
Helicopters					
N	239	198	143	138	31
Median distance	500	400	440	500	200
% Response	30	50	55	52	84
Pooled aircraft					
N	953	910	801	368	90
Median distance	800	600	600	500	250
% Response	23	34	33	44	61

[a] On the basis of incubation dates, Michigan data were standardized to Arizona data by subtracting one month.

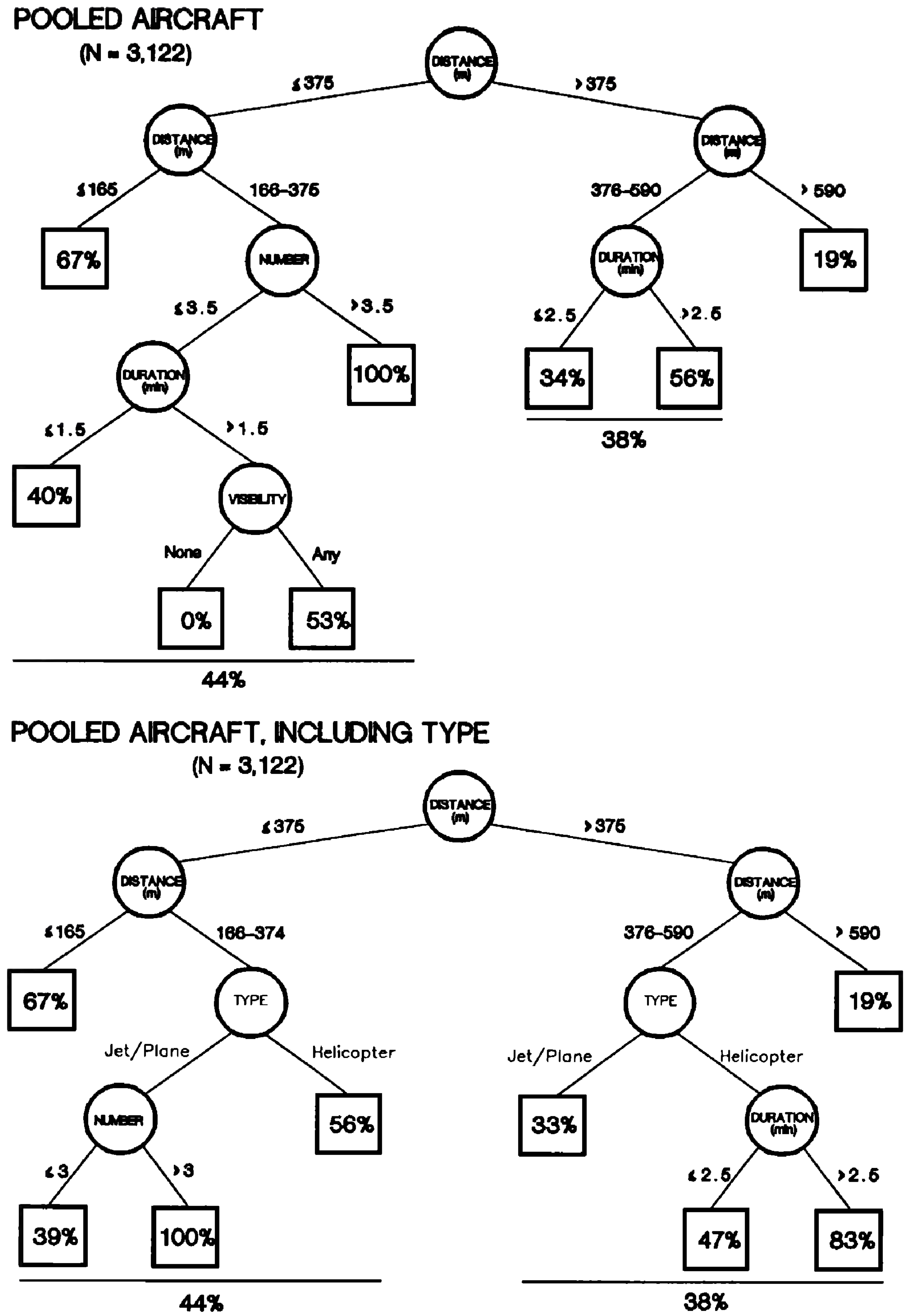

Figure 4. Classification tree (CART) models, with associated eagle response frequencies, for pooled and pooled-within-type aircraft disturbance near breeding Bald Eagles at 19 occupied nests in Arizona and Michigan, 1983–85 and 1989–90, respectively.

tance was the primary and secondary splitting variable, followed by number, duration, and visibility on the left (high-response) side of the tree, and duration alone on the right (low-response) side. When aircraft type was included as a variable in the pooled tree, it entered the model at the tertiary level, after the two distance splits. Type influenced response rates in the midrange distances (166–590 m), with helicopters partitioned from and showing greater response rates than jets and planes. Re-

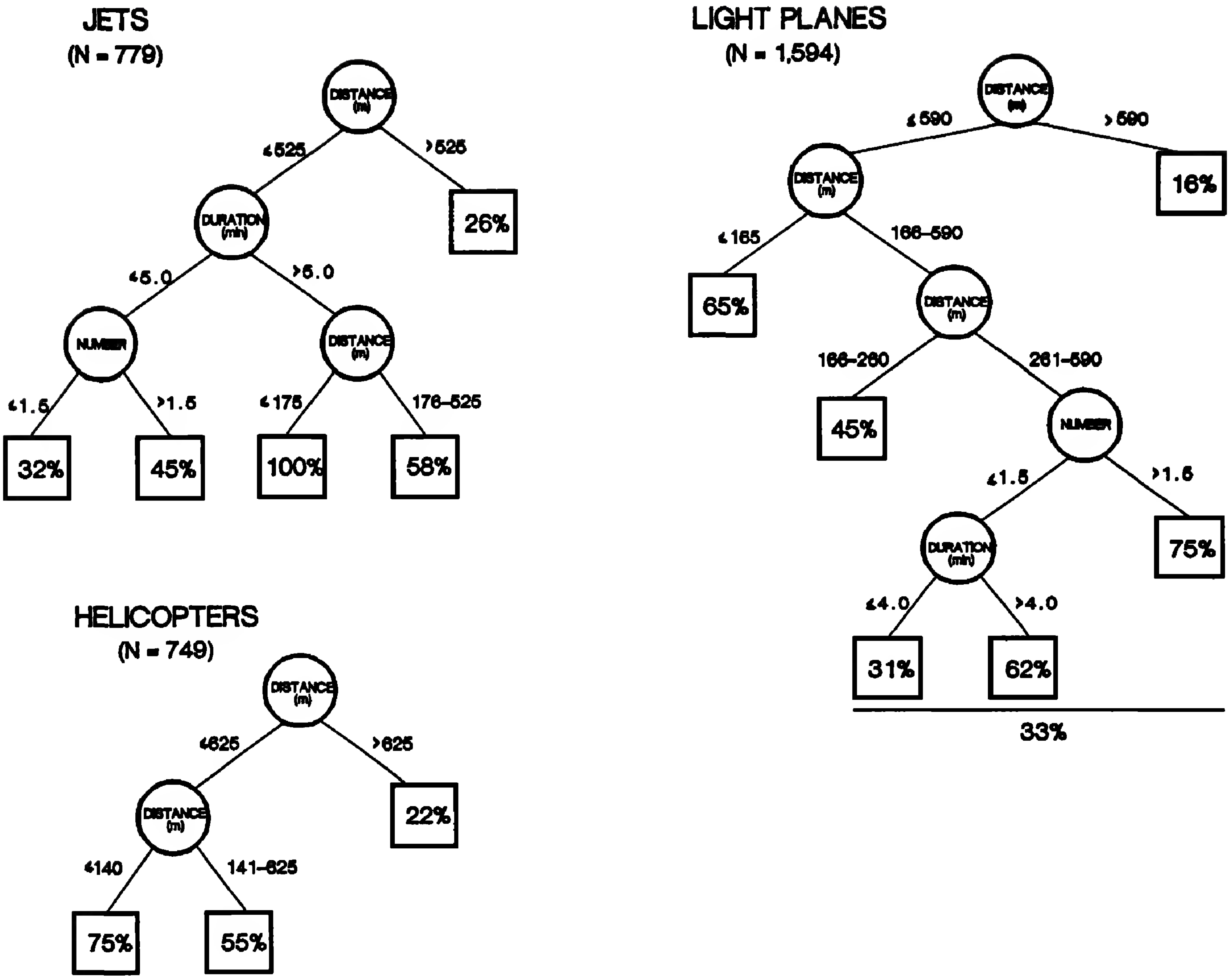

Figure 5. Classification tree (CART) models, with associated eagle response frequencies (%), for military jet, light plane and helicopter disturbance near breeding Bald Eagles at 19 occupied nests in Arizona and Michigan, 1983–85 and 1989–90, respectively.

sponse rates for both models were 67% at ≤165 m, 44% at 166–375 m, 38% at 376–590 m, and 19% at >590 m (χ^2 = 4179, $P < 0.01$). Estimated accuracy for the pooled and pooled-with-type models was 0.63.

Although CART-generated, initial splitting distances increased from jet fighters, through light planes, to helicopters, the low-response side of individual models showed light planes causing the least response at greater distances (16%) and jets the highest (26%, Fig. 5). For jets, short overflight duration (≤5 min) and single aircraft appeared to mitigate the effect of proximity within 525 m, whereas longer duration within 175 m caused certain response. Calculated response rates based solely on distance were 52% at ≤175 m, 37% at 176–525 m and 26% at >525 m (χ^2 = 398, $P <$ 0.01); the first two rates differ from the CART model because of the incorporation of duration and number within 525 m. Jet model accuracy was estimated at 0.60.

Light planes within 165 m elicited 65% response regardless of any other factors; between 166–260 m, response rate dropped to 45%. Response rates at 261–590 m and at >590 m were 33% and 16%, respectively (χ^2 = 3888, $P < 0.01$). Between 261–590 m, >1 plane or pass/event or >4 min duration caused response greater than or equal to close proximity events. Response to helicopters simply decreased as distance increased: 75% at ≤140 m, 55% at 141–625 m, and 22% at >625 m (χ^2 = 399, $P < 0.01$). Accuracy estimates for the light plane

Table 4. Relative importance[a] of independent (splitting) variables in CART analyses for three types of aircraft disturbance, treated separately and pooled with/without type included as a variable.

	Disturbance					
Variable	Pooled	Pooled with Type	Jets	Planes	Helicopters	Overall Ranking
Distance	100	100	100	100	100	1
Duration	28	36	61	26	35	2
Type	–	24	–	–	–	–
Number	17	–	39	14	6	3
Visibility	7	8	5	8	8	5
Position	6	8	11	10	8	4

[a] Standardized so primary splitting variable = 100% and secondary variables are expressed as a percentage of the primary variable.

and helicopter models were 0.61 and 0.70, respectively.

CART modeling verified distance as the most critical determinant between response and no-response associated with aircraft (Table 4). Duration-of-overflight was a consistent second and number-of-units-per-event third. Both duration and number appeared nearly twice as important for responses to jets as for the other types of aircraft. Number had the least effect on response to helicopters. Overall, position and visibility affected eagle responses to aircraft very little. When included in the pooled model, aircraft type was ranked third behind distance and duration.

Discussion

These results are necessarily qualified by the fact that sample data were not evenly or randomly distributed across the various parameters measured or among nest sites. Thus, the distribution of sample data should be considered when interpreting or applying our results. For example, repeated aircraft observations on many of the same eagles may have reduced the observed variability, frequency and/or severity of response. However, inherent limitations are at least partially mitigated by the size of the data set, the number of eagles and nest sites involved, the duration of the study and the standardization of aircraft and response measurements among types.

Greater stimuli typically result in Bald Eagles reacting farther away (Grubb et al. 1992). Thus, helicopters might be expected to cause eagle responses at greater distances than light planes. The relatively low median response distance for helicopters compared to other aircraft was more likely a result of proximate flights than an indication of breeding eagle tolerance. Helicopters, because of their enhanced maneuverability, and military jets, because of the nature of low-level fighter training, tended to follow drainages and contours (where nests were located) more closely than light planes, especially in the rugged canyon terrain of Arizona. At very close range, the consistent 200 m, calculated median flight distance for all three aircraft and the pooled-with-type CART model, which did not include aircraft type before 166 m, indicate proximity outweighs type. Comparable minimum splitting distances in each of the type models (jets 175 m, planes 165 m and helicopters 140 m) support this conclusion.

In their review of responses to aircraft by 14 raptor species, Smith et al. (1988) found the impact of low-level military jets to be brief and insignificant. In our study, jets and helicopters occurred at similar distances from nest sites. Yet, jets and light planes elicited comparable response rates at identical response distances. The fact that helicopters caused much greater response, and that CART split jets and planes from helicopters in the modeling process, argues for type differences. Also, the CART model for helicopters included no other variables than distance, suggesting a stimulus of sufficient magnitude that secondary characteristics did not influence response. Distances within the model were consistent with Platt (1977), who recorded helicopter overflights at ≤160 m altitude disturbing all adult Gyrfalcons (*Falco rusticolus*) and overflights >600 m disturbing none of the five pairs tested. Our data confirm the traditional view that helicopters are the most disturbing type of aircraft (Watson 1993).

Bald Eagles appeared least responsive to aircraft early in the nesting season, as indicated by both their lower response rate and tendency to remain at or near nests without flying. Increasing response rates, especially for flight, later in the season suggest adults were more frequently flushed as their nest attendance requirements diminished. Watson (1993) noted presence of young nestlings led to reduced adult response. He also found eagles with small young were more reluctant to flush in adverse weather, and eagles were disturbed at higher rates when no young were in the nest. Decreasing sample size over time is partially attributable to reduced adult presence near nests, which typically declines as nestlings mature (Bowerman 1991).

Grubb and King (1991) concluded breeding Bald Eagles in Arizona may have become habituated to aircraft, and in Michigan habituation was also evidenced at one nest site near a military air base (Grubb et al. 1992). Our current analysis of the combined data set indicates variability among nest sites, with an inverse relationship between frequency of air traffic and frequency of eagle response. If habituation occurs with repeated exposure, then our results may underestimate Bald Eagle response at nest sites with limited air traffic and overestimate at sites with a high frequency of aircraft.

The relative importance of CART splitting variables indicates that managing distance, duration and number of aircraft overflights could effectively minimize impacts on breeding Bald Eagles. The higher values for duration and number with jets may be a result of the tendency for military jets to fly in groups of two or more, as well as the proximity of the one Michigan nest (No. 19) to an Air National Guard, air-to-ground firing range where repeated overflights were common (Grubb et al. 1992). The relative importance of type in the pooled-with-type model validates using individual aircraft models to refine distance and potential management considerations.

Cross-validation indicates our CART aircraft models should correctly predict breeding eagle response for two of every three aircraft events. Model accuracy might be improved through controlled experimentation and by the addition and/or refinement of independent variables, including consideration of specific eagle activity (Grubb and King 1991, McGarigal et al. 1991, Watson 1993) and weather conditions (Schueck and Marzluff 1995) at the time of overflight. Significance and intensity of prestimulus eagle behavior, as well as time of the year (e.g., breeding versus nonbreeding season) may also be important factors (Smith et al. 1988).

Management plans for nesting Bald Eagles typically include restrictive buffer zones, limiting human activity within 400 m of nest sites (Grier et al. 1983). Plans may also include restrictions associated with key habitat areas such as used for foraging and perching (Isaacs and Silvosky 1981). Aircraft are typically precluded from flying within these restriction zones. CART primary splits at 525, 590, and 625 m for jets, planes and helicopters and a secondary split at 590 m on the pooled model, resulting in 19–26% response, suggest that aircraft would best be categorically excluded from within 600 m of nest sites and key habitat areas during the breeding season.

When such a categorical limitation is impractical, our CART models indicate if duration and number of aircraft and/or passes are limited to <5 min and one, respectively, jet fighters within 200 m of nest sites would cause relatively low expected eagle response (<33%). Light planes within 275 m, if limited to <4 min duration and one plane or pass/overflight, would cause 31% expected response. Avoiding helicopter overflights within 600 m of nest sites would result in a 22% expected response. However, given the advantages and therefore inevitable continued closer use of helicopters for raptor surveys (Watson 1993, Ewins and Miller 1995), we recommend these surveys be flown at maximum distance (>150 m) and minimum duration (<1 min), with only one overhead pass. Whenever possible, surveys are better conducted with light planes, because they typically cause minimal disturbance to breeding Bald Eagles (Fraser et al. 1985).

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